Climate-responsive residential buildings in India. Just a drop in the ocean?

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1. Introduction

All around the world, cities enhance their economic, cultural and social attractiveness increasing population and infrastructures. In a global context of climate change, the urban area's environmental footprint and sustainability need to be investigated and monitored, in the attempt to find strategies to reduce negative effects. Concerning climate changes, recent world climate reports stress the increasing severity and duration of heat waves. These increases will likely be more strongly felt in urban areas due to the urban heat island effect (UHI) that leads cities to have higher air and surface temperatures compared to rural areas. Pollution plays a negative role that is not only difficult to control but also affects health and aggravates heat-related climate change impacts. UHI effects and heat waves are likely to increase future energy demand. In the United States, for example, an estimated 3% to 8% of annual electricity use is required to reduce UHI effects (Ruth and Gasper, 2008). To face rising temperatures there often is no other solution than using air-conditioning. That leads to a vicious circle, as massive air conditioning has been shown to increase UHI effects up to 1 °C (Hallegatte et al. 2008). Moreover, the expansion of the air-conditioning market has increased the electrical energy consumption and peak power demand (Givoni 1994; Chiesa et al. 2014). This trend has an important effect on the GHG since the emission factor for electricity consumption is high, as shown for Europe in the specific technical annex to the SEAP template (European Commission, 2010). While the developed countries seem to increasingly engage such issues, developing countries have to face the challenges of a fast growing population and increasing economic activity with a lower availability of basic infrastructures and a relatively young capital of skills and knowledge. The air-conditioning market in emerging countries is rising quickly, with a 70% growth in the past 5 years (Dalkin Industries, 2015).

Indian big cities show all the above-mentioned problems: pollution, extreme temperatures and increasing use of A/C together with a general and exponential growth of energy consumption. The rapid economic development of India means an increase of the standards of living and expectations of the middle classes. Per capita consumption is exploding due to the rising equipment rate fueled by the motivation to reach comfortable conditions (Fernandes, 2006), namely those that are considered "basic" in Western countries (A/C, washing machine, dishwasher, laptop, refrigerator). This leads to serious environmental but also functional problems, i.e. energy shortages that can affect thousands and even millions of people, as happened in July 2012 (over 300 million people affected).

To date, a ferocious construction rhythm and qualitatively poor and climate-inadequate architectural solutions characterize the building sector in India. Residential buildings mostly share the same typology, with thin walls, lack of shading systems, and lack of insulation especially on the roof. They are vulnerable to the high tropical temperatures and to extreme climate event, harboring at the same time a rising demand for better levels of thermal comfort coming from the middle classes. For that reason, they are quickly shifting toward total dependency on air conditioning, with consistent effects on energy consumption, health and urban climate.

2. Objectives and methodology

Our study proposes low-cost strategies to improve the quality of a widespread residential building typology in Koltata (3-4 stories buildings). The proposed solutions are applicable to new constructions. The term "quality" makes here reference to buildings' capacity to control the indoor environment and assure occupants' thermal comfort whit moderate energy consumption. The choice was made to privilege architectural and technical solutions, and behavioral adaptations in order to avoid total dependency on air conditioning.

The residential building sector in India appears to be the third energy consumer, but its importance is expected to rise due to the growing rate of urbanization and equipment. In a climate-changing scenario, residential buildings will play an important role at the urban scale. This study sets out to overcome the architectural scale to reflect on a possible generalization of its results at the larger urban scale for the city of Kolkata.

To this purpose, in the first place we carried out a study on Kolkata buildings' typologies based on the analysis of a database referencing all buildings sanctioned under Kolkata Municipal Corporation from January 2000 to December 2009. This allowed us to establish the percentage of 3-4 stories buildings built during this period.

We then drew on a study based on the analysis of two flats of a one 3-4 stories building in Kolkata. The identified low-cost and technically simple interventions (such as insulation, double-glazed windows, shading overhangs, but also improved night ventilation) were tested through simulations and results were compared to a baseline case study (whose model was validated thanks to *in situ* measures recorded with data loggers). Energy Plus was used to model two flats.

We finally simulated the energy consumption for these two flats imaging a use of A/C to reach a comfort temperature of 26°C. We compared these benchmark cases to different cases combining the already identified interventions. We then calculated the correspondent energy gains. Using a theoretical estimation, we applied these results to the totality of the 3-4 stories buildings sanctioned in Kolkata from January 2000 to December 2009, to give an general idea of the possible reduction of energy consumption.

3. Kolkata residential buildings typologies.

From January 2000 to December 2009, the number of new residential buildings sanctioned under Kolkata Municipal Corporation area was 34258 on a total of 40016. 98,2% (n = 33669) of these building are of four floors or below, and 51% (n = 17485) are 3-4 stories buildings (Tab. 1). During the same period, 5349 additions (superelevations) to existing buildings were also sanctioned, mostly concerning 1-2 stories buildings. In many cases, where the norms allow it (mainly depending on two parameters, i.e. the dimension of the road in front of the building and the area of the plot), 3-4 stories buildings are replacing the existing ones. As a results, 90% of climate responsive 1-2 stories buildings from the 60's (equipped with sun screening, thick walls, vegetation and trees shading facades and flat roofs) already disappeared in Kolkata. The 3-4 stories building typology is going to become the norm across the country, and it has been estimated that it will soon represent one third of the surface of the main cities [39]. This trend is confirmed by the Kolkata database. As shown in Tab. 1, 1-2 stories buildings sanctions decreased of 47% from 2000 to 2009, while 3-4 stories buildings sanction increase of 146%. If we extend these trends and theoretically project them at 2014-2015, we can see that 1-2 stories buildings considerably diminish, while 3-4 stories buildings increasingly continue to be built.

Building TYPO	N.	% TOT	2000-1	2002-3	2004-5	2006-7	2008-9	% (2000-1 /2008-9)	2014-15	Addition to existing
1-2 st.	16184	47,2	4029	3636	3131	2057	2117	-47%	290	3937
3-4 st.	17485	51	1749	2702	3665	3083	4311	146%	5850	1369
5-10 st.	493	1,5	22	35	61	46	54	145%	81	26
11-20 st.	79	0,2	3	11	16	18	15	400%	28	11
21-55 st.	17	0,1	1	2	3	2	3	200%	6	6
TOT	34258	100	5804	6386	6876	5206	6500			5349

Tab 1. Number of residential building sanctioned by KMC from 1999 to 2010 according to their number of stories. Authors' elaboration from primary sources by KMC.

4. Simulations results and energy consumption savings

4.1 Case study

Simulations with Energy Plus concerned two flats (one at the second floor and one at the third floor under the flat roof) of a 3-story building localized in the Jadavpur area in the South part of Kolkata (Fig 1a and 1b). This building was built in 2009 and it is a very good example of new residential building stocks in this city. It is characterized by a framed structure in reinforced concrete, 20-cm-thick external and 7.6-cm-thick internal brick walls, cement mortar plaster, cement-based painting, marble floors and a flat roof insulated with a lime terracing. Windows are single-glazed with aluminum frames and no fixed shading devices. Two flats were equipped with data-loggers. The first one – named Flat 1 for simulations - is a 67.7 m^2flat on the last floor under the flat rooftop. The second flat – Flat 2 in simulations - is on the second floor, East and has a surface of 62m^2

A one-month monitoring was conducted in March 2011 by using two data-loggers positioned in the living room of each flat. The monitored data are air-temperature and relative humidity collected with a one-hour interval. Since external conditions were not directly monitored, the recorded data by the Regional Meteorological Centre, Alipore, Kolkata were used.

Figure 1a: Picture of the west facade. Figure 1b: Picture of the interior.

4.2 Model validation

The building, the general context and the two selected apartments were modeled in Design Builder in order to perform dynamic energy simulations in *EnergyPlus*. This model constitutes the benchmark of the study and was validated on experimental data. The validation occurred principally by varying internal load schedule and natural ventilation parameter. The habits of the occupants were fairly well known, but not recorded. Hence the occupancy scheduled has been set up considering available information on the real occupants, and finely adjusted on the basis of simulation output. During measurements, Flat 2 was occupied by a family of 2 adults and 2 adolescent sons, while in Flat 1 only one of the author was resident. Table 2 illustrates the final occupancy schedule for the two flats.

		Kitchen	*Bathroom*	*Bedroom*
2nd floor flat	*06:00-07:00* – 0.25 *07:00-09:00* – 1.00 *09:00-19:00* – 0.25 *19:00-22:00* – 1.00 *22:00-00:00* – 0.25	*07:00-08:00* – 0.50 *11:00-12:00* – 1.00 *18:00-20:00* – 1.00	*07:00-10:00 – 1.00* *19:00-23:00* – 0.20	*00:00-07:00* – 1.00 *07:00-09:00* – 0.50 *21:00-22:00* – 0.25 *22:00-23:00* – 0.50 *23:00-00:00* – 1.00
3rd floor flat	*00:00-01:00* – 0.25 *06:00-07:00* – 0.25 *07:00-09:00* – 1.00 *09:00-13:00* – 0.75 *17:00-19:00* – 0.25 *19:00-23:00* – 1.00 *23:00-00:00* – 0.25	*06:00-07:00* – 0.25 *07:00-09:00* – 1.00 *09:00-10:00* – 0.25 *10:00-13:00* – 1.00 *18:00-19:00* – 0.25 *19:00-22:00* – 1.00 *22:00-00:00* – 0.25	*07:00-10:00 – 1.00* *19:00-23:00* – 0.20	*00:00-07:00* – 1.00 *07:00-09:00* – 0.50 *21:00-22:00* – 0.25 *22:00-23:00* – 0.50 *23:00-00:00* – 1.00

Tab. 2 Occupancy schedule used in simulations, zero for other hours.

The validated model shows very low discrepancies from the monitored data, representing the real building behavior. For the flat on the 3rd floor, more than 70% of calculated temperatures differs from the monitored data by less than 1°C, while this result rises to almost 90% for the flat on the 2nd floor. In both cases, a difference between calculated and monitored data higher than 2°C interests only less than 1% of the considered hours.

The validated model is used for simulating different retrofitting technologies considering their influence on the energy behavior of the two flats.

4.3 Simulation of possible interventions

Among different possible interventions, four solutions and their articulations were chosen for simplicity and low cost and are listed below:

1) selective glass;
2) blind; 1. outdoor blind; 2. indoor blind;
3) Insulation of walls; 1. low insulation level (5 cm); 2. medium insulation level (15 cm); 3. high insulation level (25 cm);
4) natural ventilation; 1. night ventilation; 2. daytime ventilation; 3. 24h ventilation.

Each strategy was simulated in Energy Plus by modifying the validated model according to the specific intervention. In order to compare these strategies, the Cooling Degree Hour index (CDH) was used. CDH is defined as the sum of hourly differences between indoor air temperature and the comfort temperature, which in this specific case is assumed to be fixed at 26°C.

$$CDH = \Sigma(T_{in,op} - 26) \quad (1)$$

Figure 2 shows the CDH results for each strategies applied to the 2nd floor flat, while Figure 3 illustrates the CDH values for the 3rd floor apartment.

According to these figures, the reduction in the Cooling Degree Hours is evident for the majority of the chosen strategies, especially for the flat of the 3rd floor, where the roof effects significantly the energy demand for cooling. In the flat at the 2nd floor, only strategies 1, 2.1, 2.2, 4.1 and 4.3 show a reduction in the CDH. In this specific case, blind, selective glasses and night ventilation are very effective and could reduce the number of cooling degree hours above 26°C. For the flat of the 3rd floor, the more effective strategies are the number 1 and the two natural ventilation strategies that include night ventilation (4.1 and 4.3).

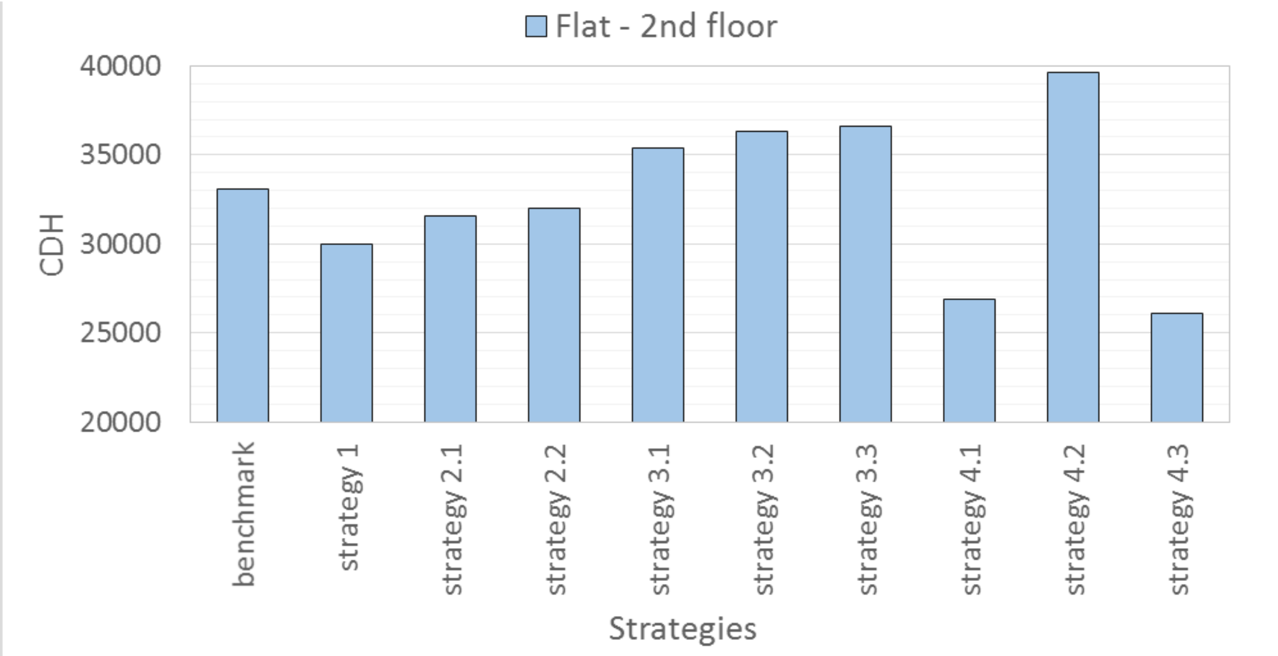

Fig. 2 CDH results for each chosen strategy applied to the apartment at the 2nd floor.

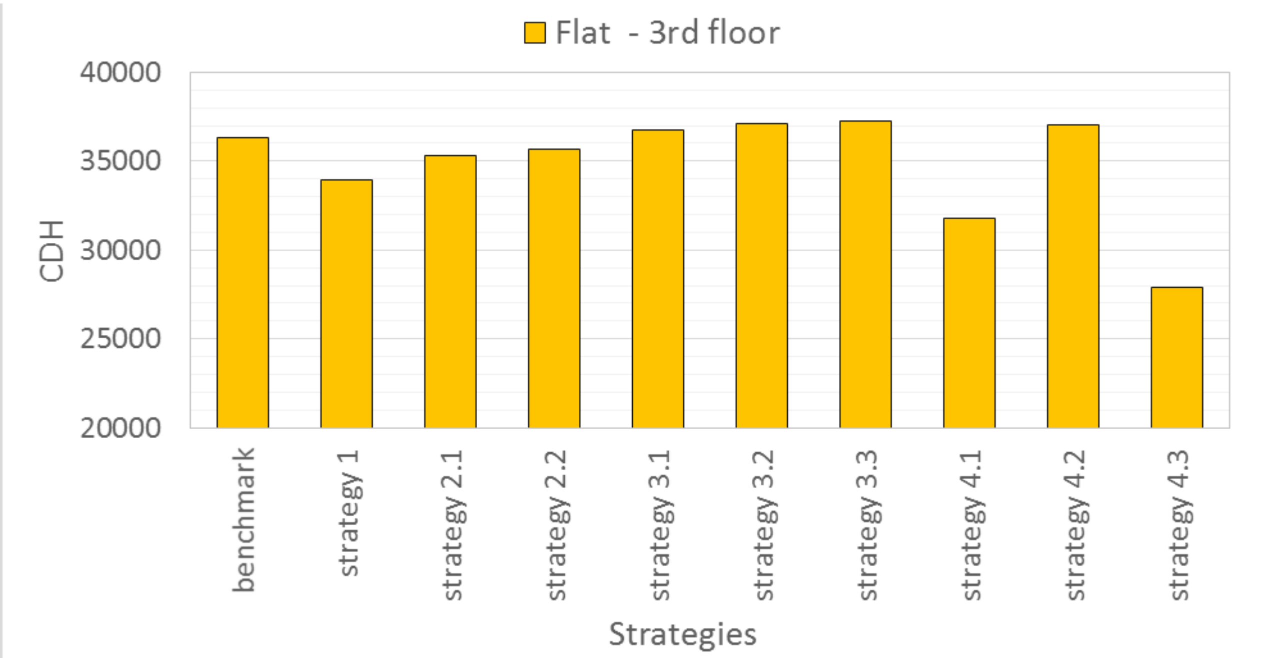

Fig. 3 CDH results for each chosen strategy applied to the apartment at the 3rd floor.

Strategy 3, insulation of walls, does not reduce the cooling requirement of the building, but even increases this value. This is probably due to the high impact of solar gains through windows in this building typology. Furthermore, daytime ventilation is not a good solution considering the high ambient air temperature during daytime and the nocturnal release of heat by thermal masses. Night ventilation is more efficient and can considerably reduce the CDH by dissipating the heat using the night ambient air as thermal sink. A 24-hours natural ventilation, nevertheless, is the more effective strategy since it allows continuous heat dissipation through air.
This analysis does not take into account people's perception and does not consider specific comfort indexes such as the TSI. However, these analyses will be reported in a future study.
The difference between the benchmark cooling need and the cooling demand for the other solutions considered could be evaluated by comparing the respective CDH results. Table 3 shows the percentage of reduction or increment in cooling demand for different strategies. This percentage could be seen as a general expected variation factor for different strategies in comparable building types and floors (intermediate or under roof).

Strategy	% of CDH variation (2nd floor)	% of CDH variation (3rd floor)
None (Benchmark)	0%	0%
Strategy 1	-7%	-9%
Strategy 2.1	-3%	-5%
Strategy 2.2	-2%	-3%
Strategy 3.1	+1%	+7%
Strategy 3.2	+2%	+10%
Strategy 3.3	+3%	+11%
Strategy 4.1	-13%	-19%
Strategy 4.2	+2%	+20%
Strategy 4.3	-23%	-21,00%

Table 3. CDH variation from the benchmark of each floor. Positive values correspond to an increase in the cooling degree hour index.

4.4 Reducing A/C consumption

The chosen interventions are relative to indoor spaces without air conditioning. However, if we envisage to use a mechanical system to perform indoor comfort a cooling energy demand in electricity can be calculated by using EnergyPlus. The mechanical air conditioning mode considers a set point of 26°C and an availability of 24/24h and employs the compact system model of Energy plus. Once an hourly net cooling demand is calculated by the software, the electricity demand is derived off line, considering the performance of a typical air cooling multi-split system. The results of the free running simulation are expressed in what follows in terms of comfort indoor degree hours, while for mechanical air conditioning the estimated electricity consumption of A/C is outlined. The benchmark model, that is the validated model run with test reference year, has been added to an air conditioning mechanical system, and the results are considered as a baseline for air-conditioned scenario (A/C base). In this way, the effect of the combined interventions are evaluated in a natural and in an air-conditioned scenario. In the chosen example, cooling A/C energy demand is 1971 kWh for the 2nd floor apartment, and 3947 kWh for the 3rd floor apartment, If combined cooling strategies are used, consumption is reduced by 76% in the 2nd floor apartment (465 kWh), and by 35% in the 3rd floor apartment (2546 kWh). These values refer to dynamic simulations performed with the same A/C system configuration but using a reflective painting finishing coupled with strategy 1 and strategy 2.2. In the 3rd floor apartment, a reflection factor has also been applied to the roof surface.
The use of simple interventions can reduce the energy need for A/C. Alternatively, if free running is used the differences in temperature between indoor air and comfort set point can be reduced.

5. Theoretical estimation of energy gains for the recently-built 3-4 stories buildings.

The use of A/C is not as widespread in India, but it is increasing. McNeil and Letschert (2008) calculated that, from 2005, the number of households using air conditioning is growing at 13-14% per year. Another source (Roy et al, 2011) proposes similar results starting from observed data concerning the number of A/C (Tab. 4).

Air conditioners	2000	2001	2002	2003	2004	2005	2006	2007	2008	2014
Roy et al.	5,6	6,4	7,2	8	8,9	9,9	11,1	12,3	13,7	17,5
% of increase (1 year)		14,30%	12,50%	11,10%	11,30%	11,20%	12,10%	10,80%	11,40%	
% of increase (9 and 14 years)									144,60%	212,50%

Tab. 4 Number of air conditioners (millions) in India. Authors' elaboration for percentages and 2014 prospective.

Let us now take up the analysis of buildings built from 2000 and 2009 in Kolkata (point3). As we said, a number of 17484 3-4 stories buildings were sanctioned during this period. We calculate from this trend that other 5850 have possibly been built from 2009 to today, or a total of 23334 3-4 stories building in 15 years. Usually this type of building hosts from 2 to 4 flats on each story, that means from 6 to 12 flats for a 3 story building and 8 to 16 flats for on 4 story building. Approximating the partition between 3 and 4 stories building as half and half, we obtain a total of flats varying from 163338 to 326674. And this is only the number of new flats in 3-4 stories building in Kolkata, a minuscule part of the total building stock of the city. If we calculate the kWh consumption of these flats imagining that they are shifting to a dependency on A/C and referring to the simulated data of consumption of point 4.4, w we are in a position to assess the severity of the problem. Even if the largest majority of households only use A/C in the bedroom, the importance of reducing the use of this equipment is pressing. As demonstrated, combined low cost solutions could be a way out.

6. Conclusions.

As demonstrated by the simulations, low cost interventions can drastically reduce the energy consumption for cooling when A/C systems are installed, and decrease temperature discomfort when no A/C system is present. Natural ventilation (strategy 4.1 and 4.3) can drastically reduce discomfort. This strategy can be easily put in place in the existing building stock by controlling air openings. Moreover, outdoor blinds and selective glasses are good low-cost solutions for reducing discomfort situations.

On the whole, the use of combined strategies can reduce the total energy demand for cooling when A/C is used. These strategies, even if simple and related to single interventions in a building, can have a large impact on the aggregated energy consumption of the building sector, especially if applied to 3-4 stories buildings. When occupants of an apartment adopt one or more strategies they only reduce their consumption or improve their comfort: they are just a drop in the ocean. But if thousands of drops arrives to the ocean, the total energy consumption will be reduced significantly.

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